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14. ABSTRACT

This report results from a contract tasking SOREQ Nuclear Research Center as follows: This work shall demonstrate the feasibility of an inventive method for a quantitative determination of residual strength of a punctured mechanical element due to holes perforated by many solid fragments. The research program will examine polycarbonate materials. The effort will build a material dependent damage function for all values of the area density of the holes, in particular for the dense populations whose behavior is previously unknown. The damage function will relate the average value of the residual strength of the element to the area density of the holes. Based on theoretical considerations, the damage-function will be formulated as a semi-analytic function with experimentally determined material constants. Moreover, the results will be the represented in a form useable by structural strength and vulnerability computer codes.

15. SUBJECT TERMS
EOARD, Ballistic Impact, Fracture mechanics, Mulit Site Damage, Composites, Polymers

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CHW

Degradation of Mechanical Properties of Multi-Perforated Structural Elements

Re: SPC 02-4052

As a part of our effort to investigate the degradation of mechanical properties of various polymers, we got hold of several possible samples of various types, of which three were of the same structure, having a roughly semi-cylindrical shape, about 1.5m long and of about 0.6m diameter. These samples were with an outer ¼" layer of PMMA and an inner ¾" layer of polycarbonate (PC), with about 0.7 mm thick transparent glue in between. On these three samples we had carried out a total of five explosive tests, two tests utilizing the "radial" charges (RC) manufactured originally for the USAF (as per the approval of Dr Mayer) and a series of three tests – utilizing a specially developed directional fragment accelerator (DFA). The RC has three sections of fragments, each section accelerated by a different amount of explosive, resulting in three different velocities: around 320 m/s, 440 m/s and 540 m/s. The fragments used were Tungsten cubes of about 4mm size, having a weight of about 1 gram each. The ejection angular spread of the fragments varies with the velocity, thus resulting in different hits density on the targets. Suffice it to say that we planned on "high" "medium" and "low" densities. The DFA accelerates a group of the same fragments to a velocity of about 850 m/s, and the hits density varies as a function of the stand-off of the charge from the target. Here, again, the hits density was classified only as "high" "medium" and "low". The actual hit densities were measured after the tests (see the table below).

In each one of the RC tests, the samples were impacted on their sides, at three different impact velocities and hits densities. Each one of the DFA was use on the top of a sample, with the same impact velocity but with different hit densities, due to different stand–offs.

The following table gives the stand-offs, impact velocity and planned hits densities of the various tests.

For the Radial Charges:

AQ F04-11-1284

Sample No.	Test No. 1 Stand-off [m]	Test No. 1 Velocity Range	Test No. 1 Density Range	Test No. 2 Stand-off [m]	Test No. 2 Velocity Range	Test No. 2 Density Range
1	0.6	320 m/s	Low	0.495	320 m/s	High
2	0.6	440 m/s	Medium	0.565	440 m/s	High
3	0.6	540 m/s	High	0.73	540 m/s	Low

For the Directional Fragments Accelerators:

Sample No.	Stand off [m]	Velocity Range [m/s]	Expected Density [Frags/m^2]	Expected Energy Density [KJ/m^2]
2	1.3	850m/s	Medium	~450
3	1.5	850m/s	Low	~250
1	1.6	850m/s	Very Low	~150

The tests were carried out on December 3-4, 2003.

The damage to the samples has not been analyzed yet, and as yet, we do not have rigorous criteria for damage quantification. However, we can already say that the lower velocity impacts created a more wide-spread, "global" damage than the higher velocity ones, even at lower hits density. This is due to long range cracking of both the PMMA and the PC. With the higher velocity impacts the penetration holes in the PC (not in the PMMA) tended to partly "mend" themselves, with very little cracking.

It seems that maximum damage is created when the hits are at an impact velocity close to the ballistic limit, almost regardless of the hits density (once it is higher than a certain, as yet undetermined, threshold value).

The actual, measured, hit densities and damage descriptions are given in the following tables.

Serial Number	Sample Number	Test Number	Charge Type	Stand-Off [m]	Measurement Pattern	Measurement Area [m^2]	Number of Hits	Hits Density [Hits/m^2]	Velocity Range [m/s]	Nominal Energy Density [J/m^2]
1	1	1	RC	0.6	Rectangle	0.1008	107	1060±20	320	55±5
2	1	2	RC	0.495	Rectangle	0.0767	123	1600±30	320	80±8
3	2	1	RC	0.6	Rectangle	0.0798	101	1265±25	440	125±12
4	2	2	RC	0.565	Rectangle	0.0756	122	1615±30	440	155±15
5	3	1	RC	0.6	Rectangle	0.0510	90	1765±35	540	255±25
6	3	2	RC	0.73	Rectangle	0.660	82	1240±25	540	180±18
7	2	3	DFA	1.3	Circle	0.0531	57	1075±20	850	390±40
8	3	3	DFA	1.5	Circle	0.0531	39	735±15	850	265±25
9	1	3	DFA	1.6	Circle	0.0594	38	640±10	850	230±25

Serial Number	Damage Description
1	No perforation, even of the front, thin, PMMA layer. Craters and cracks only. Some of the fragments were embedded in the front layer and the rest fell off it
2	
3	Full perforation of the front, PMMA layer. The fragments stopped at the glue, bonding the two layers. The inner, PC, thick layer was cracked, probably due to the impact of large pieces of the charge and not by the actual fragments. Intensive de-lamination.
4	
5	Some of the fragments perforated both layers, causing shallow craters (~ 2mm) in the aluminum witness plates. Long range, cooperative cracking in both layers, but more intensive in the front, PMMA layer.
6	
7	Perforation of both layers and of the 6mm aluminum witness plate, and ~2mm craters in a second witness plate. Only short range cracking of both layers around the penetration holes. The PC shows a certain degree of dilation around the penetration holes, so that they were partly closed, but not sealed.
8	
9	

Attached are a few photos illustrating the tests set–ups and the resulting damage. The images are slightly manipulated to enhance contrasts and to better view the hole and crack patterns.

Sincerely,

Zeev Jaeger

Yoav Me-Bar

Menahem Siman

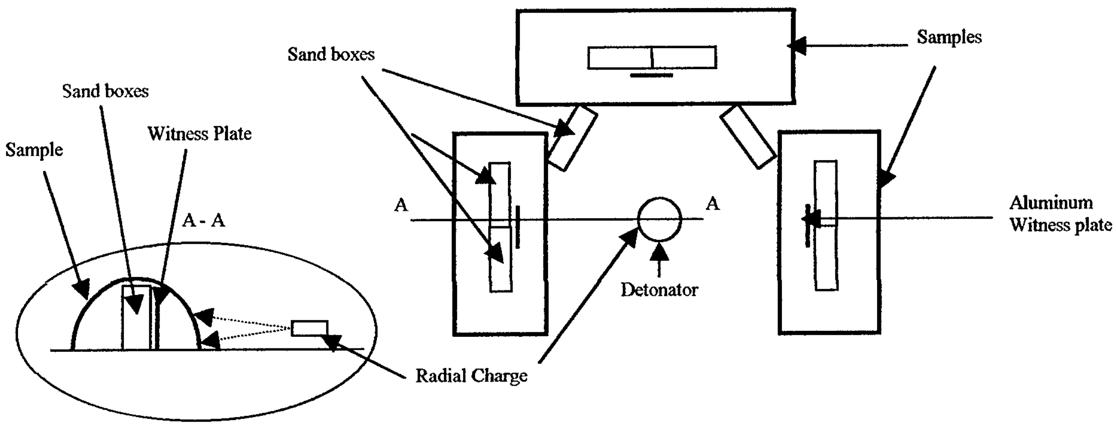

Figure 1 – Schematic illustration of the arrangement of the RC tests
(test nos. 1&2 – top view).

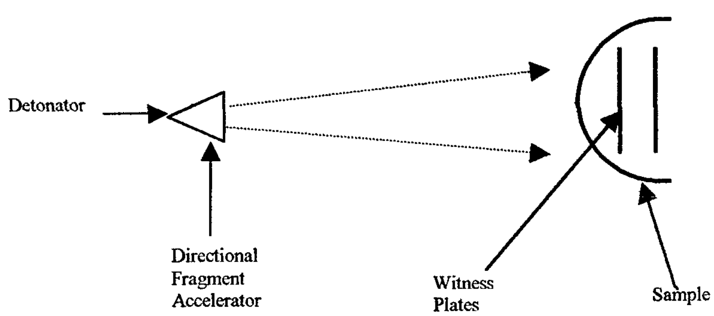

Figure 2 – Schematic illustrattion of the arrangement of the DFA tests (test series 3).

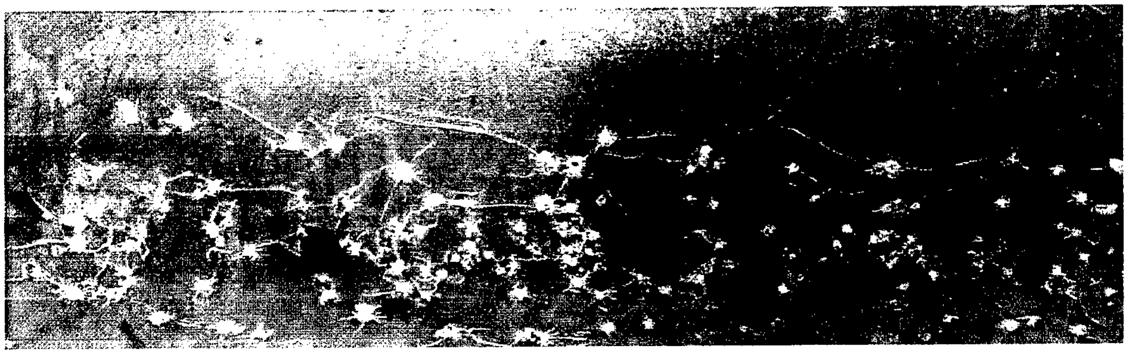

Figure 3 – The damage to sample 1 in test 1 (serial no. 1)

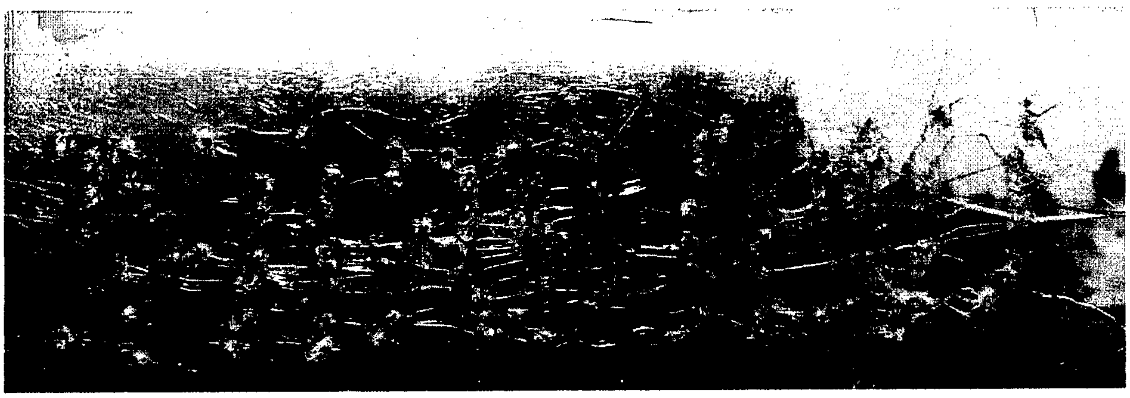

Figure 4 – The damage to sample 2 in test 1 (serial no. 2)

Figure 5 – The damage to sample 3 in test 1 (serial no. 3)

Figure 6 – The damage to sample 1 in test 2 (serial no. 4)

Figure 7 – The damage to sample 2 in test 2 (serial no. 5)

Figure 8 – The damage to sample 3 in test 2 (serial no. 6)

Figure 9 – The damage to sample 3 in test 2 (detail, serial no. 6)

Figure 10 – The damage to sample 1 in test series 3 (1.6 m, serial no. 7)

Figure 11 – The damage to sample 2 in test series 3 (1.3 m, serial no. 8)

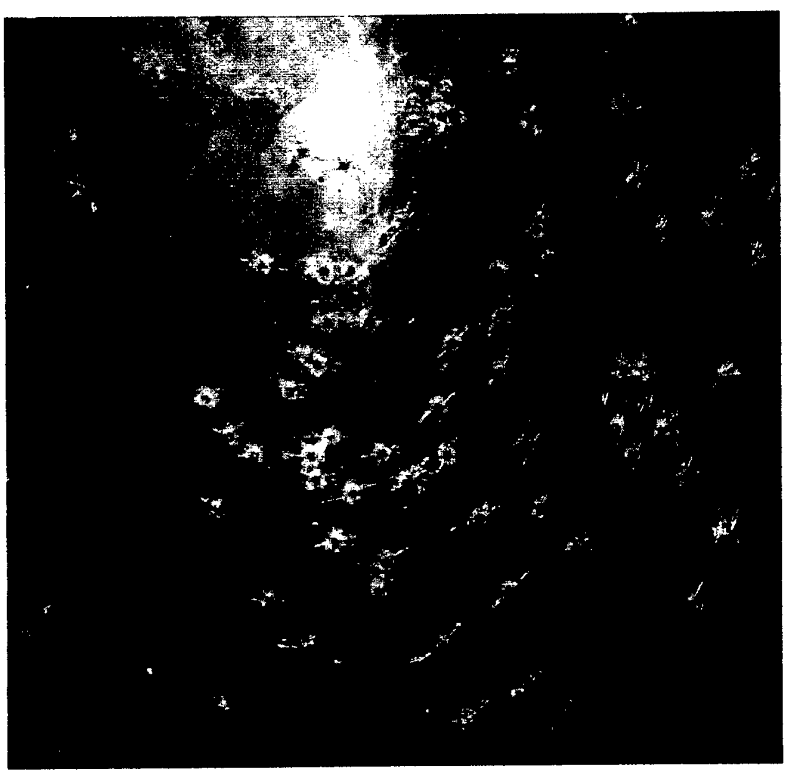

Figure 12 – The damage to sample 3 in test series 3 (1.5 m, serial no. 9)